ART. XX.—*Osmosis: the Forces by which it is accomplished, and its Agency in various Physiological and Pathological Processes, and in the Action of Medicines and Poisons.*

1. *De l'Endosmose des Acides.* Par M. DUTROCHET, Membre d'Académie des Sciences. Mémoire lu à l'Académie des Sciences le 19 Octobre, 1835.
2. *Endosmosis.* By H. DUTROCHET, M. D. In Encyclopædia of Anatomy and Physiology, by R. B. TODD, M. D. London, 1837.
3. *Lectures on the Physical Phenomena of Living Beings.* By CARLO MATTEUCCI, Professor of the University of Pisa. Translated under the Superintendence of Jonathan Pereira, M. D., Vice-President of the Royal Medical and Chirurgical Society. Philadelphia, 1848. Reprint.
4. *Researches on the Chemistry of Food, and the Motion of the Juices in the Animal Body.* By JUSTUS LIEBIG, M. D., Professor of Chemistry in the University of Giessen. Edited by Wm. Gregory, M. D., Professor of Chemistry in the University of Edinburgh, and Eben N. Horsford, A. M., Rumford Professor in the University of Cambridge. Lowell, 1848.
5. *Report on the Laws according to which the Mixing of Fluids and their Penetration into Permeable Substances occur, with special reference to the Processes in the Human and Animal Organism.* By JULIUS VOGEL. Chemical Reports and Memoirs of the Cavendish Society. London, 1848.
6. *On Phial Diffusion.* By Prof. GRAHAM. Philosophical Transactions. London, 1850.
7. *Liquid Diffusion applied to Analysis.* By THOMAS GRAHAM, F. R. S., Master of the Mint. Philosophical Transactions, Vol. 151, for 1861.
8. *Elements of Inorganic Chemistry.* By THOMAS GRAHAM, F. R. S. L. and E. Edited by Henry Watts, B. A., F. C. S., and Robert Bridges, M. D. Second American edition. 1858. Chapter "Osmose."

SINCE the experiments of Dutrochet on the subject, Osmosis has attracted much attention on the part not only of physicists, as a portion of natural science, but of physiologists, pathologists, and practitioners, who have sought aid from it in accounting for the molecular movements of the body, and in explaining the *modus operandi* of medicines. Although Dutrochet, of late years, has the merit of placing the two phases of osmosis, under the names of endosmosis and exosmosis, prominently before the scientific public, he cannot be considered as having been the first experimenter with regard to it. In the *Histoire de l'Académie des Sciences*, 1748, the Abbé Nollet directed attention to the passage of liquids of different composition through the membrane which separated them. The subject at this time occupies a more important position than formerly, because it is now known that a greater number of forces enter into the operation than was originally supposed. In treating of this subject at present, it is with the intention of bringing to bear upon medicine the assistance that has been furnished by the eminent investigators whose results have so largely contributed to our

knowledge, and of presenting as clearly as possible the *rationale* of the process of absorption in the living body.

It is stated by Matteucci that "there is no fact which demonstrates the existeuce of free extremities in the ramifications of bloodvessels, which everywhere present a very close and continuous reticulated structure. The arterial network is uninterruptedly continuous with the venous network, which in general preponderates over the former. The lymphatic system, likewise, never terminates by independent extremities, but everywhere presents the aspect of a very fine and close trellis-work. Anatomy, which agrees with physiology, leads us to the couclusion that the first part of absorption can be effected only by the aid of the porosities proper to the structure of organized bodies. In this way the absorbed matters arrive at and are mixed with the blood, the chyle, and the lymph, and are carried away by these liquids, and distributed over the body." The above quotation is the embodiment of the doctrine now entertained by physiologists, and as there are no defined perforations or mouths to the vessels admitted by them to exist, it is necessary to have recourse, for the purpose of explanation, to the property found in connectiou with all porous substances, viz., that of physical imbibition, which has been termed, when presented in organic tissues, by Dutrochet, *endosmosis* or *endosmotic* action. The reverse of this, or exudation, has been called *exosmosis*. As the phenomena of both of them are dependent on the same forces, as will be shown hereafter, it has been proposed by Prof. Graham to adopt the term *osmosis*, which is from the Greek word οσμος, impulsion, and which includes both series of phenomena.

It may be remarked that Magendie and Foderé rejected the idea of absorption by any other mode than by imbibition. The latter, in his researches upon exhalation and absorption, calls the first transudation, and the latter imbibition, which his experiments prove.[1] The idea of exhalant vessels in connection with that of open absorbent vessels has been abandoued. Porosity is a characteristic of living as well as of inanimate matter, and, as remarked by Matteucci, it will be readily admitted that capillary actions must exercise a great influence over the functions of the tissues of animals and vegetables, when we reflect that the interstices and the capillary tubes of the tissues have a diameter of from $\frac{1}{100}$ to $\frac{2}{100}$ of a millimetre (from $\frac{1}{1540}$ to $\frac{1}{5080}$ of an inch).[2]

It must be understood that capillary action is not the sole cause of absorption in living tissues, but that it conduces to it by affording the means by which fluids can enter through the interstices of the tissues. The animal membranes must be sufficiently porous to be moistened, or suck into their interstices by capillary attraction the fluid presented. But capillary attraction cannot produce motion beyond the limits of the solid body with which it is connected, and there are other forces operative, which must be taken into the calculation in the endeavour to explain the process.

OSMOSIS.—The simplest definition that has been given of the phenomena connected with this operation is the one by Matteucci of endosmosis, that "it is the mutual action of two liquids on each other when separated by membrane."[3] When osmosis takes place in the living body, the animal tissues are penetrated by fluids (either simple or charged with soluble matters) which are brought into contact with them, and all animal membranes

[1] Recherches Experimentales sur l'Exhalation et l'Absorption. Read before the Institute, and published. Paris, 1824.

[2] Lectures, p. 31.

[3] Lectures, p. 45.

are more or less pervious, so as to permit the transmission of fluid or aid in its accomplishment. This, however, takes place in accordance with laws which are determined by the character of the fluids and the structure of the tissue. The pheuomena of osmosis are arranged into two series, manifested by a stronger and weaker curreut. The first of these correspond with *endosmosis*, and the secoud with *exosmosis*.

When the subject first attracted the attention of physicists, several hypotheses were given to account for the process. The fact most conspicuous was that when two fluids of different specific gravities were separated by membrane, there existed a tendency on the part of the lighter one to pass to the denser, and this naturally suggested the idea that the latter exerted an attractive influence. Indeed, the direction towards denser fluids of lighter ones renders the porosity of animal membranes most conspicuous. Thus, if a section of fresh chicken's intestine be tied at one end, then half or three-quarters filled with a solution of sugar, and, after being tied at the other end, thrown into a vessel of clear water, in a little time it will become distended, the water passing into the intestine so as to augmeut the sugary solution.

It was suggested that viscidity is the cause of the attraction, but this conjecture has been proved to be erroneous by an experiment of Dutrochet with a solution of sugar and one of gum-Arabic. If corresponding weights of sugar and of gum be dissolved in the same weight of water, the viscidity will not be uniform; that of the gum solution will be greatest. Now, if these be separated by membrane, the direction of the current will be in excess from the gum solution to that of the sugar; and this will be the case if the strength of the former be doubled, the specific gravities then being as 1.023 to 1.014.

Another violation of the rule that specifically lighter fluids pass to the denser is exhibited by alcohol and ether, which are of less specific gravity than water, and yet the latter passes the membrane to them. In the instance of vegetable acids we have a remarkable illustration of the same fact. Thus, a saturated solution of oxalic acid, sp. gr. 1.045, at 77° F., when placed in contact with water separated by membrane, passes to the latter, with augmentation of its bulk and a diminution of its own specific gravity. This experiment was constant in its results, and it appeared that the denser the solution the stronger was the current. Citric and tartaric acids are more soluble than oxalic, and a denser solution can be made of them. When solutions were made of sp. gr. 1.05, it did not appear that an attraction for water existed so as to lead to augmentation in the bulk of the solutions, but there was a reciprocal penetration of the water and the acid through the membrane. At a sp. gr. above 1.05, the water passed to the acid solution, and below this density, as in the case of oxalic acid, the acid solution passed to the water.[1] It is evident from these results that density *per se* is not a cause of the increase of bulk in connection with endosmotic movement.

The question which presented itself to Dutrochet was, whether the power of ascension in capillary tubes is in any way a measure of endosmotic force, and whether it coincided with the facility of penetration. It has been stated that water passes to alcohol and ether, and both of them have less ascending power than water; while solutions of the acids mentioned, having less ascending power than water, when below the sp. gr. of 1.05, pass to the water. This, then, does not throw light upon the subject any more than

[1] Dutrochet. Mémoire.

does the rapidity of penetration through capillary tubes or membrane, for it was found by Liebig that a solution of gum was less readily filtered through a capillary tube than one of sugar; and yet, when even of double the strength, the former augments the latter through membrane. The solution of oxalic acid was found to filter through membrane less rapidly than water.[1]

The cause of osmosis to be first examined is that connected with *imbibition* by animal membranes, or the capillary absorbing power with respect to fluids, and this has been found to vary with different liquids. It may be characterized as an *affinity* of membranes for fluids, which is diverse. Pure water is readily imbibed by membrane, while the absorbing power for solution of salt diminishes in the ratio of saturation of the solution. A mixture of water and alcohol is taken up also in proportion to the dilution. Liebig found that 100 parts of ox-bladder take up in 24 hours—

Of pure water	268 vols.
" saturated solution of sea salt (brine) . . .	133 "
" alcohol of 84 per cent.	38 "
" oil of marrow	17 "

And 100 parts by weight of ox-bladder take up in 48 hours—

Of pure water	310 parts by weight.
" mixture, $\frac{1}{3}$ water, $\frac{2}{3}$ brine . . .	219 " "
" " $\frac{1}{2}$ " $\frac{1}{2}$ " . . .	235 " "
" " $\frac{2}{3}$ " $\frac{1}{3}$ " . . .	288 " "
" " $\frac{1}{2}$ alcohol, $\frac{1}{2}$ water . . .	60 " "
" " $\frac{1}{3}$ " $\frac{2}{3}$ " . . .	181 " "
" " $\frac{1}{4}$ " $\frac{3}{4}$ " . . .	290 " "[2]

When *Endosmosis* takes place, there must be a superior affinity between the interposed membrane and one of the fluids, or, in other words, for one of them the membrane must possess a greater imbibing tendency. If alcohol be confined in a bladder, and exposed to the atmosphere, the water passes through the bladder and evaporates, thus concentrating the alcohol; but when a membrane of India-rubber is used to separate water and alcohol, the alcohol penetrates the septum, and passes to the water. In these examples we have illustration of an elective affinity on the part of membranes.

Imbibition through membranes varies in accordance with the surface which is exposed to the entering liquid. If the most porous surface be placed in contact with it, the entrance of the fluid will be promoted. If the reverse be presented, the introduction of the fluid will not be so active; and should the most porous surface be brought in contact with alcohol or

[1] Difference in passing through a capillary tube :—

Equal quantity of water	time required,	157 seconds.
" " " Sol. of sugar, sp. gr. 1.014,	" "	159 "
" " " " gum, "	" "	262 "
" " " " " " 1.023,	" "	362 "

In filtering by gravity, at 69° F., the time being the same :—

Water passes to the extent of	24 parts.
Solution of oxalic acid, sp. gr. 1.005	12 "
" " " " 1.01	9 "

This was the result when each fluid was placed above the same fluid, but separated by membrane.

[2] The same facts were presented when experimenting with pig's bladder. Researches on the Motion of the Juices of the Animal Body, by Justus Liebig, p. 135. (*Op. cit.*)

coagulating solutions, the probability is that a restraining influence will be exerted from a change iu the surface by the action of such fluids.

Pressure exercises an influence upon the passage of fluids through membranes, aud the degree of it required for different fluids has been found to be varied.

In experiments upon the force required to produce the passage through membranes when simply moistened by the fluid, it was found by Liebig that this depends upon the thickness of the membrane, and that through ox-bladder $\frac{1}{10}$ of a line in thickness—

Water requires a pressure of . . .	12 in. of mercury.
Saturated solution of salt	18 " "
Marrow oil	34 " "

When the membrane used was the peritoneum of the calf, $\frac{1}{20}$ of a line thick—

Water required a pressure of . . .	8.10 in. of mercury.
Solution of salt	12.16 " "
Marrow oil	22.24 " "
Alcohol	36.40 " "

Alcohol, then, the most limpid fluid, and having the least specific gravity, requires the most pressure.

From the above experiments it appears that the amount of pressure required is inversely as the force of capillary attraction; that is, where the greatest capillary attraction exists, there less pressure is required.

The force of capillary attraction is in many cases so great as to be capable of equipoising a considerably opposing force. If, for instance, a glass tube be so tightly closed by bladder that no fluid can penetrate between the glass and the animal membrane, and if it then be filled with water, the capillary attraction of the bladder will retain the water with so much tenacity that the pressure of a column of water several feet high will not be able before a period of several hours to force any appreciable quantity of water through the bladder, and many days, or even weeks, will intervene before a column of water several inches in height, and whose base covers the surface of the bladder, will be able to penetrate through the membrane. The resistance of capillary attraction is not, however, absolute, as the pores may be unequal. The simplest exhibition of capillary force is in the case of water rising iu blotting-paper in opposition to gravity,[1] and it is apparent from experiments that the mechanical influence exercised by a permeable substance upon the fluid penetrating into it consists in the fluid being attracted by the substance with a force that opposes a certain resistance to other mechanical forces acting on the fluid, as gravity, hydrostatic pressure, &c.[2]

When fluids of similar properties are separated by membrane which is permeable, if the hydrostatic pressure be equal on both sides, no change will occur. If, however, the pressure be stronger on one side than the other, a certain quantity of the fluid under pressure will pass to the other.

[1] Vogel, Chemical Reports and Memoirs, Cavendish Society, pp. 93, 94.

[2] This force has been recognized and applied to the purposes of lifting weights and splitting rocks.

Different kinds of filters furnish examples of the varied manner in which mechanical capillary force acts in individual cases. If a fluid be poured into a funnel, it will run through more rapidly than when it has first to pass through a filter. In the latter case the impediment is afforded not only by the opposing solid body, but by the resistance of the capillary attraction in the interstices or pores. In many filters this is considerable. (Vogel, *op. cit.*, pp. 93, 94.)

This quantity will correspond to the excess of pressure on the one side, allowing for the resistance opposed to the pressure by the mechanical capillary force.[1]

Mucous membrane readily permits the passage of liquids. That of the stomach of the dog, the cat, and the lamb, and of the bladder of the ox were employed by Matteucci and Cimma in their experiments. With the different solutions used, the position favourable to endosmotic action was from the interior to the exterior surface, and between the two there was greater variety than with the skin of the eel, the frog, or torpedo.[2]

The following conclusions were arrived at from the experiments of the above named experimenters :—

"1st. The membrane interposed between the two liquids is very actively concerned, according to its nature, in the intensity and direction of the endosmotic current.

"2d. There is, in general, for each membrane a certain position in which endosmosis is most intense, and the cases are very rare in which with fresh membrane endosmosis takes place equally, whatever be the relative position of the membrane to the two liquids.

"3d. The direction which is most favourable to endosmosis through skins is usually from the internal to the external surface, with the exception of the skin of the frog, in which endosmosis, in the single case of water and alcohol, is promoted from the external to the internal surface.

"4th. The direction favourable to endosmosis through stomachs and urinary bladder, varies with different liquids much more than through skins.

"5th. The phenomenon of endosmosis is intimately connected with the physiological condition of the membranes.

"6th. With membranes dried, or altered by putrefaction, either we do not observe the usual difference ensuing from the position of their surfaces or endosmosis no longer takes place."

Another phase of osmotic action is that which has been referred to as *Exosmosis*. While there is a tendency on the part of a lighter fluid to pass to a denser one through membrane, the denser may pass to the lighter and alter its specific gravity. Thus, while water passes through the parietes of a fowl's intestine to augment the sugary liquid solution contained in it, the sugary fluid itself will pass outwards to mingle with the water, and this to the greater extent as the intestine becomes distended.

An experiment, the reverse of that detailed in illustrating endosmosis, may be performed with the intestine of the fowl. If a section be completely filled with water, and thrown into a solution of sugar, the intestine will be partly emptied by the abstraction of the water, while the remaining water contained in it will assume the taste of sugar and greater specific gravity. If a portion of the intestine of a fowl be filled with a watery solution of gum Arabic and rhabarbarin, and when tied close, laid in a vessel of water, the intestine becomes tensely distended, and the rhabarbarin exudes from it. Similar experiments may be performed with albumen or saline substances.

Prof. Jolly, of Heidelberg, exhibited the same exosmotic phenomenon by the following experiment: A saline solution, containing a known quantity of salt, was placed in a glass tube, closed at the bottom with bladder; this was placed in water, frequently changing it to keep it pure. The tube and its contents were taken out from time to time, and weighed. This was repeated until the weight was constant. The absence of the salt was thus

[1] Vogel, op. cit., p. 93.

[2] Matteucci, Lectures.

demonstrated, and nothing but water remained.[1] Exosmosis and endosmosis, as will be exhibited hereafter, are both dependent upon the same principles; and we may regard exosmosis as it has been represented above, as analogous to the operation which has been termed dialysis by Prof. Graham.[2] But, while it is admitted that membranes have the power of imbibing fluids by capillary attraction with a force which differs for the several liquids, there exists a displacing power exerted by one fluid upon another, which frequently is at variance with and in direct opposition to the force with which a fluid is attracted by membrane, and it appears that those which even have less facility of being imbibed may displace others for which the affinity on the part of membranes is stronger. This is illustrated by the experiments of Liebig.

He found that 100 parts of animal membrane (dry ox-bladder) absorb in 48 hours 310 parts of water and only 133 of saturated solution of salt. If when saturated with water it be strewed with salt, a saturated solution of salt is formed which replaces the water. It follows therefore that as membrane has a capacity for 310 parts of water and for only 133 parts of the saline solution, there is a diminution of the absorbent power of the bladder to the extent of 177 parts, which are expelled, and run off in drops. A similar effect of reduction of fluid will take place if the membrane holding water be brought in contact with a solution of salt. "Membranes, fibrin, or a mass of flesh behave exactly in the same manner when in contact with alcohol. If placed in alcohol in the fresh state, that is, when they are thoroughly charged with water, there are formed at all points where water and alcohol meet, mixtures of the two; and as the animal texture absorbs much less of the alcoholic mixture than pure water, more water is expelled than of alcohol taken up."[3]

In connection with such displacement as is here exhibited there must be and actually is shrinking of texture. If the results presented in these examples depended solely upon capillary attraction, the anomaly would be presented of a weaker force overcoming a greater, inasmuch as the imbibing power is superior on the part of membrane for water to that for brine or alcohol.

The very opposite to the facts which have been stated is also found to occur. Thus if we tie over one end of a cylindrical tube a membrane (bladder) saturated with concentrated brine, by steeping for twenty-four hours, and if we dry the outer surface of the membrane carefully with bibulous paper, and now pour a few drops of pure water into the tube, so as just to cover the inner surface of the membrane; the outer surface is seen in a few moments to be covered with minute drops of brine; that is, brine flows out of the pores of the bladder. Mr. Whitelaw has detailed some experi-

[1] Elements of Chemistry. By Prof. Graham.

[2] In the case of exudation, pressure is an important element of power; under its influence in the vessels there must ensue the loss of fluid, as is illustrated in diarrhœas, dropsies, &c.

[3] 9.17 grammes of fresh bladder contain 6.97 grammes of water, 2.22 of dry ox-bladder; when placed for 24 hours in 40 c.c. of alcohol, the weight is 4.73 grammes, there has consequently been a loss of 4.44 grammes. In the 4.73 grammes which remain there is the 2.22 of dry bladder, and only 2.51 of liquid. If we assume that this liquid has the same composition as the surrounding mixture 84 per cent. of alcohol to 16 of water, it will consist of 2.11 grammes of alcohol and 0.40 of water, and therefore of the 6.97 grammes of water originally present, 6.45 have been expelled and replaced by 2.11 alcohol. For one volume of alcohol retained more than three of water have been expelled. (Liebig, *op. cit.*, 137.)

ments on the removal of the salt in brine contained in salted beef, by soakin sea-water until the beef becomes comparatively fresh and expands like a sponge, resuming a part of the natural juices from the brine.[1] In these cases is exhibited the preponderating force of attraction for the fluid (pure water or a weaker solution of salt) for which there is the greatest affinity on the part of the membrane.

There can be no doubt, from the foregoing statements, that an important element in the displacement that occurs when brine or alcohol are brought into contact with water contained in membrane, so that the membrane retains a less amount of the mixture than of the water is the diminished absorbing capacity of the membrane, or less affinity for the mixture. The displacement, in the interstices of the membrane, of a fluid for which the membrane has greater affinity, by one for which it has less, cannot depend upon a cause residing in the membrane itself, other than the diminution of capillary attraction or power of imbibition.

It is evident that membrane has an attraction for fluids, or an affinity for them which varies for each, yet in the case of each is definite. If the membrane, therefore, has imbibed a fluid, and another is brought in contact with it so as to form a compound of the two for which the membrane has greater attraction, this will take possession of the membrane to the exclusion of the first contained in it. Thus, if the membrane contain a saline solution or alcohol and be brought into contact with water, and there be dilution of either fluid, the greater amount taken up of the diluted fluid would appear to depend upon the superior capillary attraction for that fluid which thus becomes the displacing fluid. Where contraction has taken place under the entrance of the first fluid, expansion will be brought about by the introduction of the second. But the reverse of this is also the case. If the membrane has imbibed a fluid and another is brought into contact with it, so as to form a compound fluid for which the membrane has *less attraction*, the fluid for which there is the *greatest affinity* is displaced, and the new one takes its place. A solution of salt will displace pure water, as has been seen, and the same is the case with alcohol. By sprinkling salt on moistened bladder the solution of salt formed will enter the intestines of the bladder to the exclusion of the water, which will appear in drops on the surface.[2] Meat is salted by sprinkling the salt upon the surface, and this operation is attended with contraction of fibre and loss of juices. It may be assumed, therefore, that as the displacement overcomes and is in opposition to superior capillary attraction, there is a *new force* brought into operation, and this is the *affinity* between the *two liquids* or of the liquid for the substance (salt for example) placed in contact with the membrane, which affinity is greater than that of the membrane for the fluid which it most easily imbibes. *If there be no affinity between fluids, the one for which the membrane has the least attraction will not take the place of the other, will not displace it.*

It is assumed by Liebig that the "relation of bladder, fibrin, and other animal substances, when saturated with water, to alcohol and brine, proves that the shrinking of these tissues does not depend upon the abstraction of water in consequence of the affinity of alcohol or salt for that liquid, as it is certain that the attraction of alcohol for water or water for alcohol are respectively equal. The attraction of water within the tissue for alcohol

[1] Dublin Medical Press, June 22, 1864. Med. News, Phila., Aug. 1864.
[2] Liebig, op. cit.

without, is just as strong as the power of the alcohol without to combine with the water within. Less alcohol is taken up and more water given out because the animal tissue has less attraction for the mixture of alcohol and water than for pure water alone."[1] So far as it goes, this statement is correct, but does not meet the difficulty of explaining why a less affinity on the part of membranes supplants a greater. It must be that the attraction of water for alcohol or of alcohol for water is superior to the attraction of the membrane for water, and hence it parts with it, and the alcohol without becomes diluted, while the water within becomes mixed with a certain proportion of alcohol. Hence it is that "this exchange is only arrested when the attraction of water for the animal tissue and its attraction for alcohol counterpoise each other."

In the case of fibrin or membranes containing alcohol or salines when brought into contact with water, the capillary attraction for the water being greater than for the alcohol or the salines, they can be displaced by it, yet the process is greatly facilitated by the power possessed by them of combination with water.

In all the cases that have been given, there is a power of combining between water and other liquids, a capacity of union between them which plays an important part in the phenomena of imbibition. But there are other instances in which the property of combination does not exist; thus Chevreul determined that when tendons and ligaments saturated in oil were placed in water, the oil is completely expelled, and they take up as much water as if they had not previously been in contact with the oil. Now as there is but the feeblest affinity between the oil and the water the introduction of the latter must depend upon the greater affinity of the membrane for it.

A dried bladder continues hard and brittle in alcohol and oil, its flexibility is in no degree increased by absorbing them. Although these fluids can be displaced from membrane by water, they can be assisted in their own introduction by it. In the case of oil, water may act by expanding the capillary pores, thus facilitating the entrance along with it. The fact is well known and acted upon by curriers, that by working and pressure moist leather can be made to take up more oil than dry. Again, leather that has been exposed to moisture becomes hard and dry by the expulsion of the oil, and before re-oiling it the surface should be sponged or moistened with water. In the filtration of oily matters it is best to moisten the filter so that the oil shall not clog the pores of the material used. In this way the oil can better pass through the pores which are moistened by the water, adhesion to them being prevented. Oil is introduced into the lacteals in the form of emulsion or of a saponaceous compound, by which the same influence is most effective.

The attempt has been made to show that where there is a faculty of combining between water and other fluids in consequence of mutual attraction between them, the mere power of imbibition on the part of membrane is not of primary consequence, it has a secondary office, for did displacement rest upon this power it would be perfect, and no salines or alcohol be left in the interstices of the membrane; whereas the displacement is limited by the dilution of the saline or the alcohol, and the membrane holds in its interstices a weaker solution, the amount retained being governed by the dilution. In other terms the force of combination

[1] Liebig, op. cit., p. 138.

between the saline or alcoholic solution regulates the nature and degree of the imbibition. It is not the mere attraction of the membrane for water which deprives it of salines, but the diluting effect of the water on the salines, and this latter depends upon the *force of chemical affinity between them.*

The power of imbibition, which has been considered, depending upon capillary attraction, accounts for the introduction of fluid into the interstices of membrane, but not for absorption into the vessels so as to form a part of the fluid material of the circulation, for, as remarked by Liebig, "liquids flow out of capillary tubes which are filled by them, *only when some other force or cause acts*, because capillary attraction cannot produce motion beyond the limits of the solid body which determines the capillary action. We are, therefore, under the necessity of seeking for an additional force which will explain the fact of a current from without setting into the circulation. This force resides in the power of *diffusion.*

The tendency of substances to extend themselves through fluids or of fluids to diffuse themselves through each other is the foundation of *solution*, and the force which operates under such circumstances is that of attraction. The solubility of substances depends upon this attraction on the part of molecules of solid soluble matter and the molecules of the liquid in which they can dissolve, and when in solution such substances can be further diffused so as to form a more dilute solution. In proportion to the strength and energy of the attraction is diffusive mobility exhibited by different substances, and, as remarked by Graham, appears to be as "wide as the scale of vapour tensions."[1] Diffusive attraction producing solution may take place in any degree below the point of saturation, where the force of attraction has its limit. "In a mixture of alcohol and water or of brine and water there is in every part the same proportion of particles of alcohol and water and of salt and water." The attraction which exists has been placed by Liebig under the denomination of chemical affinity, although it is not attended with alteration in the character of the molecules that are interested.[2]

In the case of solution there may be manifested an elective affinity, depending on the greater facility of solution possessed by one substance over another. The most soluble substances are dissolved with the greatest velocity. Thus, hydrate of potassa may be said to possess double the velocity of diffusion through water of sulphate of potassa, and, again, double the velocity of sugar, alcohol, and sulphate of magnesia (Graham). If oil and salt are combined and water added, the larger proportion of the salt will be given up to the water in consequence of elective affinity. Liebig has given some pertinent illustrations of the same fact. If a solution of sulphate of potassa be formed and liquor potassæ be added, the sulphate will be separated, obeying the natural attraction of its particles and crystallizing, in consequence of the superior affinity of the potassa for water. Alcohol will separate a number of salines from water. When hydroferrocyanic acid is liberated from ferrocyanide of potassium in solution by diluted muriatic acid, it is held dissolved by the water, but if the vapour of ether be passed through the solution the whole of the acid is set free in the form of white or bluish-white crystalline scales, so as to become a semi-solid mass.

[1] Liquid Diffusion, Graham, p. 185, Philos. Trans.
[2] Researches, &c., op. cit., p. 150.

The same view of solution that has been presented is taken by Vogel, who states "if two fluids whose constituents chemically attract each other come in contact, they will combine and form one mixed fluid, homogeneous in its nature, of which each smallest particle will exhibit a like property. If, for instance, we mix a fluid consisting of twenty parts of salt and eighty parts of water with one hundred parts of water, a solution will be formed, the smallest distinguishable particle of which will contain nine parts of water to every part of salt." If we suppose the two commixing fluids be separated masses, then the constituent particles of each will attract those of the other, and conversely. This species of attraction is stronger than that existing between the constituents of each body among themselves. Thus, atoms will pass from *a* to *b*, and again from *b* to *a*, until both fluid masses have become chemically equal; that is, have assumed a like composition. If a lump of sugar or alum be placed in water, the particles will tend to separate and diffuse themselves, the attraction of the water for the sugar or alum, and of the sugar or alum for the water overcoming the attraction between the particles of either.

This attraction may take place laterally, and as the particles of the substance must thus pass through all the particles of the solvent until the last are reached, by transmission, as it were, from one to another, a longer time is required. The same also happens where solution goes on upwards. A downward solution is aided by gravity, as where sugar is suspended in water. If the body be heavy which is to become commingled with a fluid and has to ascend, or the material be light and floats on the solvent, a greater time must be consumed for the diffusion to be effected. For instance, a solution or a lump of salt at the bottom of a column of water will be longer in reaching the surface of the water, while alcohol, on a similar column of water, will also be longer in diffusing itself, both being in opposition to gravity. Motion, whether from heat or a mechanical cause, promotes attraction by the more rapid diffusion of molecules or the production of currents.

The degree and the velocity of diffusion possessed by different substances have been investigated by Prof. Graham, by whom most interesting results have been obtained. He has divided substances which are soluble into two kinds, *crystalloids* and *colloids*, the latter so called from their behaviour like glue in the presence of water. The results observed were in opposition to gravity, which method presents the strongest test of attracting force. To this method Prof. Graham has given the appellation of "jar diffusion;" it is practised in the following manner: A saline or other solution is placed at the bottom of a jar, and then water placed above the stratum. After a certain time the amount of the saline, which has raised itself upwards, may be determined in the various strata of water. In this way the relative attraction or solution of different soluble substances may be determined. For the sake of illustration, the following table is presented, the experiments having been conducted with two crystalloids, *salt* and *sugar*, and two colloids, *gum* and *tannin*:—

Experiments showing the diffusion of 10 per cent. solutions through pure water, after 14 days, at 50° Fahr.

	Salt.	Sugar.	Gum.	Tannin.
Stratum 1	.104	.005	.003	.003
" 2	.129	.008	.003	.003
" 3	.162	.012	.003	.004
" 4	.198	.016	.004	.003
" 5	.267	.030	.003	.005
" 6	.340	.059	.004	.007
" 7	.429	.102	.006	.017
" 8	.535	.180	.031	.031
" 9	.654	.305	.097	.069
" 10	.766	.495	.215	.145
" 11	.881	.740	.407	.288
" 12	.991	1.075	.734	.556
" 13	1.090	1.435	1.157	1.050
" 14	1.187	1.758	1.731	1.719
" 15	2.266	3.783	5.601	6.097
	9.999	10.003	9.999	9.997

The superimposed column was 4.38 inches in height, 111 millimetres in all. The first stratum of chloride of sodium contained 1 per cent., and the first stratum of sugar contained .005, which shows that the sugar had just reached the top. In the case of the gum and tannin, the seventh stratum presented decided evidences at the height of 2.2 inches. What is above that the experimenter attributes to accidental dispersion.

Experiments with sulphate of magnesia, and albumen and caromel, both colloid substances. Diffusion of 10 per cent. solutions for 14 days.

	Sulph. magnes. at 10° R.	Albumen at 13°–13°.5 R.	Caromel at 10°–11° R.
Stratum 1	.007	.000	.000
" 2	.011	.000	.000
" 3	.018	.000	.000
" 4	.027	.000	.000
" 5	.049	.000	.000
" 6	.085	.000	.003
" 7	.133	.000	.005
" 8	.218	.010	.010
" 9	.331	.015	.023
" 10	.499	.047	.033
" 11	.730	.113	.075
" 12	1.022	.343	.215
" 13	1.383	.855	.705
" 14	1.803	1.892	1.725
" 15	3.684	6.725	7.206
	10.000	10.000	10.000

This table shows the *attraction of solution* which lifts the heavy particles from the bottom, and it likewise exhibits the difference between the solubility of crystalline and colloid bodies. The albumen did not in fourteen days advance to the seventh stratum, while the caromel only reached the sixth stratum.

By the further tabulated experiments of Graham it will be found that diffusion, in relation to time, is progressive, but not entirely uniform. The longer the time, the more complete the diffusion from persistence of the attracting force; thus, with chloride of sodium, in four days the upper stra-

tum contained .004, while, as has been shown by the above table, in fourteen days it reached .104. The disparity of diffusion between crystalloids and colloids is shown in relation to time; thus, sugar advances in two days nearly as much as albumen in fourteen days. There is some disparity in point of time, when substances are compared with each other, as it appears that a fourteen days' diffusion of sugar is greater in amount than a four days' diffusion of chloride of sodium, but less than a five days' diffusion of that substance. The diffusion of chloride of sodium appears to be pretty nearly three times greater or more rapid than that of sugar. Experiments made with hydrochloric acid and chloride of sodium show that the diffusion of the first in three days closely corresponds to that of the second in seven days.[1] The rapidity of mixture or solution depends on the *degree* of chemical affinity between fluids or substances and their solvent, the mobility of the particles of one or the other having a favourable or unfavourable influence on the result; fluids or substances of tough, viscid consistence have feebler affinity, their own cohesion being with greater difficulty overcome. There is another element in calculating the rapidity of diffusion which must be taken into consideration; it is the lessened attraction as fluids imbibe the diffusing matter. According to Prof. Graham, the general law which regulates such movements with reference to salt appears to be this: "The velocity with which a soluble salt diffuses from a stronger to a weaker solution is proportional to the difference of concentration between two contiguous strata."

Substances when in solution together, so as to form a compound solution, obey the force of diffusive attraction as when they are separate, and in this case the inequality of diffusion becomes apparent if there exist a difference in the solubility. Sugar and gum, when united in solution, will diffuse themselves as shown by the table. A mixture of two salts being placed at the bottom of a jar, it may be expected that the salts will diffuse pretty much as they do when they are diffused separately, the more diffusive salt travelling most rapidly, and showing itself first and always most largely in the upper strata. The early experiments of Prof. Graham on diffusion from phials had shown indeed that inequality of diffusion is increased by mixture, and the actual separation is consequently greater than that calculated from the relative diffusibilities of the mixed substances. According to these experiments, chlorides of potassium and sodium diffuse nearly in the proportion of 1 to .841.

[1] The general results of several series of experiments may be expressed approximatively thus, with respect to time:—

Hydrochloric acid	1
Chloride of sodium	2.33
Sugar	7
Sulphate of magnesia	7
Albumen	49
Caromel	98

(*Graham.*)

Diffusion of a mixture of 5 per cent. of chloride of potassium and 5 per cent. of chloride of sodium, for 7 days, at 12°–13° R.

	Chloride of potassium.	Chloride of sodium.	Total diffusate.
Stratum 1	.018	.014	.032
" 2	.025	.015	.040
" 3	.044	.014	.058
" 4	.075	.017	.092
" 5	.101	.034	.135
" 6	.141	.063	.204
" 7	.185	.104	.289
" 8	.252	.151	.403
" 9	.330	.212	.542
" 10	.349	.351	.700
" 11	.418	.458	.876
" 12	.511	.559	1.070
" 13	.552	.684	1.236
" 14	.615	.772	1.387
" 15	1.385	1.551	2.936
	5.001	4.999	10.000

In the upper portion of the table, chloride of potassium always appears in excess, but not in so large a proportion in the first three strata as the fourth. The first six strata contain together 561 milligrammes, of which 404 mill., or 72 per cent.—that is, three-fourths—are chloride of potassium. In the lower strata the chloride of sodium preponderates, and only at the tenth stratum is there an equilibrium. Prof. Graham remarks that "the preceding experiment might be so conducted as to diffuse away the chloride of potassium, and leave below a mixture containing chloride of sodium in relative excess to as great an extent as the chloride of potassium is found above in the last experiment." From this and analogous experiments the author concluded "that by repeating the diffusive rectification a sufficient number of times, a portion of the more diffusive salt might be obtained at least in a state of sensible purity."

When an experiment similar to the foregoing was conducted with salts of the same base, as the chloride of sodium and sulphate of soda, the separation was more apparent. The six upper strata contained 90.8 per cent. of the chloride of sodium, and the upper eight strata contained 83.9 per cent.

Heat appears to promote diffusion, but does not seem to facilitate the separation of unequally diffusive substances. At low temperatures, again, diffusion is proportionally slow.

It is certain, from the foregoing exposition, that, in connection with solution, there is a force upon which depends the diffusion of the particles of soluble substances through fluids, and that this force not only lifts them, but retains them in a state of diffusion in opposition to gravity and to the disposition which they have naturally by cohesive attraction to come together. This force is always in existence where soluble substances are in contact with the solvent, and, as is seen in the tables, there is a tendency to diffusion by which the particles of both the substance and fluid unite together. This tendency is only limited by the complete and thorough diffusion of the particles, which may move in all directions; consequently saline particles may move to aqueous particles, as well as aqueous to saline, by virtue of their mutual attraction. When thorough union is accomplished, there is an *equilibrium of saturation*, the solution then being

uniform in composition. When an equilibrium is established, the addition of new fluid will again produce attraction, which will commence where the solution and the liquid meet, and will not cease to exert its influence until there has been a thorough incorporation of particles. If a liquid has taken up all of a solid with which it can combine, it is said to be *fully saturated;* but where this point has not been reached, and complete diffusion has not taken place, the force continues in operation by which this will sooner or later be accomplished. It requires only time, or may be assisted by mechanical or other means. In the production of solution there may be said to be a tendency to *uniform saturation.*

The principles of diffusion connected with solution which have been presented have an important bearing upon the process of absorption, which takes place through membranes in the animal economy. The effect of interposed membrane between fluids which have the tendency to unite and diffuse themselves is but to retard the result, the extent of surface presented regulating the extent to which mixture can take place. When a tube closed with bladder and filled with brine is left for a long time with the closed end immersed in pure water, the amount of salt in the latter increases, while that of the brine diminishes, till, at last, the two liquids, separated by the bladder, contain the same relative proportions of salt and water. It was found by Mr. Graham[1] that common salt diffuses into water through a thin membrane of ox-bladder deprived of its outer muscular coating, at the same rate as when no membrane is interposed. We may perform the reverse experiment of placing water in a tube and immersing its closed end in a solution of salt or alcohol, when the saline or alcohol will penetrate to the water.[2]

Every membrane must be regarded as a septum of capillary pores, into which the fluids can penetrate. When on one side of a membrane a liquid is placed containing a substance (a saline for example) in solution, and on the other side water, a mixture is formed in the interstices of the membrane. This mixture is a diluted state of the saline solution, and occurs in consequence of the attraction between the saline particles and water. The tendency on the side of the water is to dilution in consequence of the attraction of the membrane for water, and on the side of the saline for concentration of the solution in the membrane in consequence of the attraction of the saline for the water, or its diffusive tendency. This force then overcomes the attraction of the membrane for the more diluted liquid. There is a struggle or alternation between the two forces, viz., the superior attraction of the membrane for the diluted fluid and of the saline to diffuse itself into this fluid, and concentrate it. These are alternately operative with a changing capacity on the part of the membrane, and hence the expansion and contraction which must attend the operation of osmosis. This diffusive attraction of the salt for the water is the true reason why the membrane yields its superior attraction for the water to an inferior one for the saline solution, it is the force which displaces the water or a diluted solution with the introduction of a stronger one into the membrane, giving rise to currents and suction. Through the membrane, then, the effort of equilibrium of solution is being accomplished, which is facilitated on the side of the membrane where imbibition most readily takes place, and is retarded on the

[1] Chemistry, p. 497, Am. ed.

[2] The specific gravities of the two fluids are in all these cases changed—that of the denser fluid becoming reduced, while that of the lighter is augmented until they nearly approximate.

side where there is the least penetration; hence the greater diffusion of the more easily penetrating liquid with an increase in the volume of the liquid towards which it is directed. This is the solution of the question of the apparent superior attraction of one fluid for another on opposite sides of membrane and of denser solutions attracting lighter ones.[1]

The difficulty of explaining the introduction of articles into the circulation has arisen from the limited interpretation of osmotic phenomena presented by experiments with membranes. It has been supposed that a sensible increase in volume of fluid on one side or other, constituted the exemplification of osmotic action, and that this is under the control of affinities possessed by membrane. *The truth is that the mutual attraction between fluids, or of soluble substances for fluids, with the tendency to diffusion is the foundation of osmosis, and that the specific affinity of membrane* for fluids is *the regulator of the results which take place.* The first of these is the force which must enter into the calculation, while the latter is the modifying force by which phenomena are controlled. It is only by estimating these two forces jointly that the diversity of the effects manifested in the numerous experiments which have been made becomes intelligible.

It should be recollected that osmosis may take place both *with* and *without* increase of volume. This is an essential fact in the explanation of absorption, and where there is no increase of volume the membrane may be said to be *indifferent* or *neutral.* When a denser fluid is on one side of the membrane the current which is directed towards it is only for a time; it has its limit, and the limit is when a point of diffusion has been reached by an interchange of particles at which the membrane becomes indifferent. To a saturated solution of salt, half again of the volume will be gained of water in an endosmometer (200 parts will increase to 300), at which point the effect of the membrane appears to be lost. In this case the action of the membrane is exhibited when the surface of the membrane inclosing the saline is connected with the water by a single drop, which falls when the membrane becomes indifferent.

An exposition has already been given of the influence of pressure upon osmosis. Liebig has shown by a simple experiment that the force of attraction between a membrane and a fluid is equivalent to such pressure as can neutralize it. The experiment is performed by the pressure of mercury, which can be made to antagonize the force of attraction of the membrane for water, so that while the saline diffuses itself, there is no increase of volume. By neutralizing this force, the membrane becomes, as it were, indifferent, and takes no part in the operation, that is, becomes passive. What is equivalent to this may be produced by distension. A tube of membrane (a section of fowl's intestine) being filled with a solution of salt

[1] It has been remarked by Vogel, that where two fluids capable of being mixed are separated by a permeable substance, owing to the mutual chemical attraction exercised by the constituents of the one fluid on those of the other, both fluids will strive to become chemically equal, and this perfect admixture will always succeed as the final result of their being brought in contact, although in a shorter or longer time and attended by different accessory circumstances, whilst the volumes of the two fluids may either remain unchanged or the volume of one increase as that of the other diminishes. The only truly important practical point to be traced out in the arrangement of all experiments on this subject may be embraced in the following simple question: which constituents of the fluid *a* (as well with respect to quality as quantity) pass in a given time to *b*, and which pass from *b* to *a*? (Vogel, *op. cit.*, p. 98.)

when tied at both ends, and thrown into water, undergoes the introduction of the water into it. As the intestine becomes distended a pressure is produced upon the membrane which antagonizes the force of imbibition, and then diffusion of the salt externally goes on as if no membrane intervened. Neutrality is thus engendered.

The reverse of the preceding can also be brought about and the force of imbibition be converted into a true suction. If the membranous tube (intestine) be filled with water, then placed in a saline solution, and circulatory motion be given to the latter, in consequence of the continued renewal of the saline in contact with the exterior membrane, the water which has passed from the interior of the tube will be diffused away and rapidity given to the current. This will be equivalent to a renewal of the strength of the solution in contact with the membrane, and as the tendency is to the diminution of the current of imbibition by membrane in proportion to the fall in strength of the solution exterior to it, this is prevented, and a neutral state of the membrane does not occur.

In the accomplishment of osmosis it was assumed by Dutrochet that there is a stronger ingoing current (endosmotic) and a weaker outgoing current (the exosmotic). It has been shown by Liebig that saline and inferentially other matters, do not simply pass through membrane, without a certain amount of water, or, in other words, that these particles alone do not pass, but that there is an actual current. In liquids of different density the one placed above another, separated by membrane by colouring one of them the currents may be demonstrated.[1] The currents which are perceptible are not dependent solely upon diffusion, for in the process of concentration and dilution there is a corresponding process in the membrane of contraction and expansion; on the side of the saline or of alcohol there will be condensation and on the side of the water dilatation. The inherent elasticity of membrane conduces to these changes, and where there is an alternation of them there must be *continual motion*.

The point which constituted the anomaly in the phenomena of osmosis was the determination of the ability of fluids of higher specific gravity to pass to those of less specific gravity and even to increase their volume. That denser fluids should attract those of less specific gravity was regarded as the law and the reverse as an exception, not understood. In such an entanglement was Dutrochet and the earlier experimenters. In addition to the facts presented (page 137) the following may be given: When the two liquids are diluted sulph. acid sp. gr. 1.093 and water, the acid at 50 F. increases in volume; but if the acid be reduced to a sp. gr. 1.054, the volume of water increases. Diluted tartaric acid (11 parts to 89 water) and water mix through a bladder without change of volume, with more than 11 per cent. of the acid the volume of acid increases, with less, the water increases. It is evident from experiments that have been detailed that there is a density which is inimical to affinity for membrane, and hence the current in the direction of the fluid possessed of this density. Again, there may be a density which does not affect the affinity, so that to both the dense and the lighter fluids the membrane is neutral. In these cases the law of diffusion may prevail unimpeded, and there is an interchange without alteration in volume. Still further, there are substances which, when in solution, appear to have a superior affinity for membranes than water and a greater power of traversing them; thus oxalic acid which has a feeble power of saturation

[1] Liebig, op. cit., pp. 146–165, Am. ed.

even at that point passes to the water, and may even when added to other articles facilitate their passage, as for instance to sugar in solution. The same is the case with other acids when in solution below a certain sp. gr. as we have seen with sulphuric, tartaric, and citric acids.

It appears from experiments that a substance possessing the feeblest power of diffusion, or none at all, has little capability of being absorbed by and of passing through membrane, yet osmotic action may readily occur towards it. Thus albumen and other colloid bodies have comparatively a feeble diffusive power; and with respect to imbibition and exudation pure albumen possesses the least tendencies, which is an important circumstance, when its function in the operations of the economy is taken into consideration. It has been made obvious that with this feeble diffusive power, which is dependent upon the little comparative attraction between them and water, still the tendency of water to pass to colloids through membrane is very decided in consequence of the attraction of the water for membrane through which it passes to be imbibed by the colloid. If a clay cell or a glass tube secured by some animal membrane be filled with dried animal or vegetable matters, as fibrin, coagulated albumen, resin, mucus, &c., and put into a vessel of water, the water will penetrate through the membrane and pass from its inner surface to the substance chosen for the experiment, causing it to swell. Here no passage occurs outwards. The quantity of liquid which passes through the partition in a given time depends upon the superficies of the latter, upon the power of absorption by the interior substance, and upon its quantity. The same results will occur if instead of coloured substances some blotting paper or dried sponge be introduced into the tube, which simply exercise capillary affinity.[1]

When a solution of gelatine, of gum, or of albumen is made of the specific gravity 1.07, and exposed to the action of water through membrane, it has been found that the increase of the volume of the solution of gelatine amounts to 3, of solution of gum to 5, and of albumen to 12, which last is greater than of sugar, which is 11. Albumen, as was stated by Dutrochet, has the highest power with reference to osmosis. This explains the readiness with which water and diluted solutions can enter the circulation, for when liquids (either water or solutions) have passed the membrane, the diffusive attraction is brought into operation, and they are disseminated through the colloid matter.

Albumen is the basic colloid material of the blood, which may resolve itself into other colloid matter, as fibrin, &c. When supplied with the due amount of water, it presents the appearance of other liquids. Most authorities have taught that albumen is soluble, and consequently that it can undergo osmotic penetration. In the normal condition Dumas regarded it as miscible with water in all proportions, and only insoluble when coagulated. Berzelius regarded it as soluble; M. Denis first affirmed its insolubility and that it be dissolved by aid of an alkali. It is remarked by Mialhe "that if albumen were soluble and endosmotic, it could not maintain itself in the circulatory system, but would constantly traverse the coats of the vessels containing it, and would diffuse itself in the organism and be lost in the products of secretion." Regarding the albumen of the serum and the white of egg as possessed of the same properties, M. Mialhe experimented with both of them relatively to their osmotic properties. The membrane of the egg was used, and whether the white of egg or serum was

[1] Vogel, op. cit., p. 97.

employed, he found that no albumen exuded from the interior, although water and salines penetrated to the interior. When water is used externally, all the salines in connection with the albumen are diffused through the membrane to that liquid. Water penetrates freely to albumen in an egg so as to burst the capsule in a few hours. Mialhe found that an egg weighed 2.5 grammes more (38 grains) by the absorption of water through its denuded capsule.

The absorption of substances, whether of a nutrient or medicinal nature, must be accounted for upon the principles of osmotic penetration. The blood which circulates in the capillary vessels is rich in albumen and colloid material, through which water and such articles as are held in solution can be diffused, while it also contains salines which have an affinity for water. The power of absorption varies in the several tissues depending upon their vascularity and physical structure. There is, moreover, an element to be considered in appreciating the rapidity of absorption, which is the maintenance of the current of the circulation—were not the blood in motion, the result of endosmosis in the vessels would be very limited in amount. It is by the constant action of new liquid in the vessels, in connection with outside solutions, that absorption is maintained. It can be easily understood, therefore, that imbibition goes on, other circumstances being favourable, in proportion to the freedom of the capillary circulation. Should this be clogged or in a static condition, an impediment is presented.

In connection with absorption there are two separate acts, *imbibition* and *transmission*. By the first the fluid substance enters the bloodvessels, and by the second it is diffused, and by the circulation of the blood is directed to the heart and to the several organs of the body. As has been explained in discussing the forces by which osmosis is accomplished, the first act in the introduction of liquid into the circulation is in accordance with the affinity of the liquid for the membrane. Water can easily penetrate, and then being diffused through the albumen will circulate with it and the salines. But the question arises with respect to saline and other solutions. The same law must hold here as with other membranes. Although the capillary vessels have less affinity for saline solutions than for water, still they will penetrate in proportion to their dilution, and the difficulty of introduction will augment in proportion to the increase of their strength. By those writers who adopted the explanation derived from the experiments of Dutrochet, great stress has been laid upon the necessity of a liquid which enters the circulation being of less specific gravity than the blood. This, however, resolves itself into the greater facility with which dilute solutions can become obedient to osmotic action. The sp. gr. of the blood is 1.028, and it contains from three-fourths to one per cent. of saline matter, so that liquids of less specific gravity will be more likely to enter the vessels and be diffused, but as has been shown, for instance with respect to acids, this is not an invariable law. It is not the denser solution within the vessels which attracts the liquid without, but the lighter external liquid possessing a greater facility of penetrating the vessels, and after having penetrated of diffusing itself by the attraction between it and the liquid within. If the liquid on the outside of the vessels have a higher sp. gr. than the blood, there will be a greater difficulty of introduction into them, *but not an exclusion;* a certain quantity, though less in amount, will be imbibed by the vessels, and from them be yielded to the watery and albuminous elements of the blood; indeed, as a colloid, the albumen becomes a medium of liquid diffusion like water itself. The same explanation applies

to alcohol and ether, which in the concentrated state have little penetrating power from the feeble affinity for membrane, but acquires both by dilution.

Dr. Graham uses the term *dialysis* in its application to the method of separation by diffusion through a septum of gelatinous matter. If a solution of salines (or crystalloids) be on one side of a septum and water on the other, the tendency will be for the passage of the salines to the water, and an equalization of saturation. This will be facilitated by motion.[1] In the same way, other articles may be diffused by dialysis. If the blood, a solution weaker in salines, then be separated from a stronger solution of them, there will be a tendency to the same equalization by dialysis into the vessels, there being a constant change in the strength of the fluid circulating in them. This introduction of solutions is not confined to a single one; several articles may be dissolved in the same fluid, and as has been shown by Prof. Graham, may be jointly diffused so that it is as easy to understand the entrance of a compound solution as of a single one. In the same way may be explained the separation of the soluble composite elements of the food in the process of primary nutrition. A selection is thus effected.

Some interesting experiments, proving and illustrating the agency of the circulation, were performed by Matteucci. If a living frog be immersed by its inferior extremities only in a solution of ferrocyanide of potassium, and the animal soon after be killed, scarcely any traces of the salt can be detected in the muscles of the legs and thighs, whereas the heart and lungs give very distinct evidence of it when touched with the chloride of iron. If the animal be kept for several hours in the solution, then the viscera will be penetrated by it through the circulation; but if the animal be killed, and the hind legs immersed for a short time, the heart and lungs will not be more imbued with the salt than other parts of the body. In explanation of these experiments, he states that—

"The solution was introduced into the body of the frog simply by imbibition, and this phenomenon, being effected in the living as well as in the dead frog, certainly cannot be regarded as different from the imbibition that has been presented, which belongs both to organic and inorganic bodies, and which is the consequence of these cellular and vascular structures. But there is something more than this. In the heart and lungs of a living frog we find a much larger quantity of the absorbed solution than in the other parts of the body, although these latter were much nearer the part immersed. The viscera mentioned are the centre of the circulatory system; in them commence or terminate the trunks of the bloodvessels; the solution of ferrocyanide, therefore, penetrates the bloodvessels by imbibition, becomes mingled with the blood, thus arriving at the heart and lungs."

Another simple experiment proves the same facts. If two frogs are taken,

[1] An experiment bearing upon this point by Poisseuille may be stated. Phosphate of soda in a four per ct. solution being placed in an endosmometer and serum external to it, the solution augmented from 18 to 30–34 millimetres—after nine hours it stood at 20, and in fifteen hours at 8 millimetres. The membrane had ceased to osmose on the second day, but by shaking the endosmometer and agitating the serum the layers of liquid in contact with the membrane were altered and the osmose was renewed, the column mounted to 4 millimetres in an hour and then fell to 1. The serum of the vase was replaced by distilled water, when endosmose was renewed, and the column mounted in an hour to 54 and 60 millimetres, then in four hours fell to 54 and 48 millimetres. On the sixth day the membrane had not lost its power. This experiment is an illustration of the difference between ingoing and outwardly flowing currents, depending upon the capability of membrane. (*Comptes Rendus*, 1843.)

and from one the heart be removed, it will be found that both are active. Now, upon placing both in a large glass, containing a solution of extract of nux vomica, the animal with the heart is soon poisoned and long before the other becomes affected.

That permeability exists in living tissue, irrespective of circulation, was proven by an experiment recorded by Prof. J. K. Mitchell in his paper on the *Penetrativeness of Fluids.*[1] He there states that while engaged in investigating Magendie's theory of venous absorption, he coloured the diaphragm of a living cat blue by placing a solution of prussiate of potassa on one side, and that of sulphate of iron upon the other.

The physical conditions requisite for vital absorption are:—

1. A vessel or structure with organic sides or walls.

2. An exterior liquid capable of being imbibed by the tissue composing the walls.

3. An internal liquid, also capable of being imbibed by the walls, of intermixing with the exterior liquid, and of circulating in the vessels more or less rapidly.

From the *first essential condition* it is evident that the facility of absorption in different organs depends upon the vascularity that is present, as well as upon the flaccidity of their tissue, and the conducting property of the parts composing them. Where the greatest vascularity exists, there are the greatest number of points of imbibition, as well as a more active circulation to carry away the matters that have been absorbed. The lungs possess this power to a greater extent than any other organs, because more vascular, more delicate in texture, and having a shorter round of the circulation. The cellular tissue, on the contrary, while having the power of imbibition, is not provided with so active a circulation, and hence absorption is slower. By removing the cuticle from the skin, substances may be brought more directly in contact with the vessels, and absorption be facilitated. Mucous membrane readily permits the passage of liquids. That of the stomach of the dog, the cat, and the lamb, and the bladder of the ox were employed by Matteucci and Cimma in their experiments. The position favourable for endosmotic action was from the interior to the exterior surface. The vascularity of the mucous membrane of the alimentary canal and its great extent of surface will account for the facility possessed by it of absorbing water or fluids composed of substances in solution.

With respect to the *second condition*, an external liquid capable of being imbibed by tissue, it may be assumed that all substances, in order to secure their introduction, must be in solution, and that solid substances, no matter how finely reduced, are precluded from entrance into the tissues by imbibition. Solid articles, which are insoluble in water, are constantly employed as medicines; their exhibition being followed by decided effects upon the organs of the economy, it is clear that such articles are transformed into soluble matter by the chemical reaction which takes place between them and other elements with which they are brought in contact in the organs. A knowledge of chemical changes in the presence of other bodies has enabled us to explain the results which are obvious in such cases.

With reference to the *third condition*, it is well known that the blood fulfils all the requisites presented; its water and matters in solution are capable of being imbibed by the walls of the vessels, of intermixing with the exterior liquid, of receiving accessions from it, and of circulating in the

[1] American Journal of Medical Sciences, Nov. 1830.

vessels. The freer the circulation the more rapid the absorption, and hence a greater absorbing power exists in the veins than in the lacteals or the lymphatics.

While the blood circulates in the vessels with a given velocity, the walls of the vessels are, in the normal state, far less permeable by it than by the other fluids of the body. Should the volume of the blood increase by absorption, it is counteracted by the antagonizing action of the kidneys and other emunctories.

In estimating the circumstances favourable to the passage of fluids through membranes, it should not be overlooked that pressure is conducive to such effects. How far pressure is conducive to endosmotic action, as it is derived from the actual weight of the atmosphere, has not been determined, but it is very clear that pressure is operative in exosmotic phenomena, as is illustrated in the exudations and effusions that take place in organs. Many substances, as, for instance, the thinner animal membranes, are expanded by the pressure of the column of fluid resting upon them, and thus their efficient surface is increased, while their texture is changed, their thickness diminished, and their pores enlarged.

From the foregoing exposition of absorption we may arrive at the following conclusions:—

That the introduction of fluids containing dissolved substances is due—

1. To the force of capillary attraction which exists to a greater or less extent between membranes and fluids, which modifies the result and renders the process easy or difficult.

2. To molecular or chemical attraction between fluids of different specific gravities which are capable of being commingled and becoming homogeneous.

3. That absorption is aided and rendered active by the circulation in the vessels by which the fluids interested are constantly changed in their relation to each other.

That there are certain forces in operation in connection with cell action that must have an influence in controlling the introduction of substances becomes apparent when the difference is adverted to of selection of articles by different vessels in the same structure. Thus, oil or fatty matters when worked into emulsion or chemically altered are preferably taken in by the lacteals, while sugar and other like articles are readily absorbed by the veins. There is no doubt that these forces are not distinct from those which regulate absorption in general, and are dependent upon the same principles of explanation.

In opposition to the opinion that medicines enter the circulation, it has been alleged that their effects are produced so rapidly as to preclude the possibility of their being absorbed. The point in question has been carefully examined by Mr. Blake,[1] who arrived at the conclusion that the rapidity of the action of a poison was in proportion to the rapidity of the circulation. He found that an interval, always more than nine seconds, elapses between the introduction of a poison into the capillaries or veins and the first symptoms of its action. In dogs, a substance which does not act on the capillary tissue passes from any part of the vascular system back to the same part again in from twelve to twenty seconds. Prof. Hesing, of Stuttgard, found that the time which a solution of ferrocyanide of potassium, injected into the jugular vein, requires to reach that of the

[1] Edinburgh Med. and Surg. Journ., vol. 53, p. 24.

opposite side, was in various experiments from twenty to thirty seconds.[1] With reference to prussic acid, Dr. H. Meyer determined by his experiments that killing by this poison, although a rapid process, is by no means so instantaneous as formerly supposed, generally only after the lapse of one minute and a half, and it is well known that this is one of the most rapid of poisonous articles.[2] The argument, therefore, against the introduction of sedative poisons, based upon the time of their operation, has no intrinsic force. J. C.

ART. XXI.—*Medical Errors. Fallacies connected with the application of the Inductive Method of Reasoning to the Science of Medicine.* By A. W. BARCLAY, M.D., Cantab. and Edin., Fellow Roy. Coll. Phys., Physician to St. George's Hospital, &c. &c. 12mo. pp. 123. London: J. Churchill & Sons. 1864.

AN extensive subject is here presented; capable of occupying a much larger volume. Medical errors form *pars magna* of medical literature. Diogenes could hardly need to search longer for a man in Athens, than Stuart Mill among medical writers for a logician. Is it not the principal advance of the last century, that we have been relieved of many errors which, if they did not rule medical practice, at least burdened it greatly? A natural effect of the discovery of those errors, and of the unscientific basis of much prevailing practice, has been an era of medical scepticism, in which we now live. It is, therefore, of the utmost importance that a positive science of medicine shall be re-constituted of the materials within reach of the profession. Induction is undoubtedly essential for this reconstruction. That its principles and methods, at once scientifically correct and practically available, should be understood by all medical students, practitioners, and teachers, is of great consequence.

Dr. Barclay has, in his published lectures, strongly asserted this, and has well illustrated it by examples. It may be regretted, however, that he has not been quite so felicitous in his discussion of the philosophy of the subject. To those who have read H. Spencer, Mill, Baden Powell, and Whewell upon similar topics, much is missed of the clearness with which, even with diverse views, those masters of the logic of science deal with it.

Such a criticism ought not to be made without some citation to justify it. Much of his language is clear and correct, but sometimes words are used in a manner liable to create confusion. Thus (p. 10):—

> "While it is quite true that the hypothesis is very often suggested to the mind of the accurate observer by some harmony which arrests his attention, it is nevertheless true that in many cases it is a mere deduction; and in most of those which are classed as the highest inductions, there is a combination of both forms of reasoning, often united with an idea which is not the fruit of any reasoning process whatever, but is simply the bright offspring of genius."

Without an example of such a "bright idea"—which our author does not give—we are unable to imagine, among familiar instances of discoveries by induction, what part of any of them can be regarded as apart from

[1] Pereira, Elements of Mat. Med., vol. i. p. 154.
[2] London Medical Times, vol. ix. p. 432.